Guidelines for the Preparation of A Science Requirements Document

From the Principal Investigators (PI's) perspective, the Science Requirements Document (SRD) is the most critical document they will be asked to produce for their experiment. The SRD goes through a number of drafts (as many as 8) and is studied in more minute detail than most scientific publications. Consequently its preparation and editing is a very significant burden that consumes a significant portion of the PI's time. The SRD serves two major functions: it is the document that presents and defends the rationale for the experiment to the peer reviewers at two major reviews and it is the document that is the basis of the defacto contract between the P.I. and NASA. If the SRD doesn't provide good justification for the science then success at the peer reviews (Science concept Review (SCR) and Requirements Definition Review (RDR)) is less likely and if the SRD fails to properly define the science requirements then success of the experiment is in jeopardy. The PI is ultimately responsible for the SRD but substantial guidance is provided by the Project Scientist (PS) and others throughout the project to ensure that the SRD is as good as possible. The purpose of this document is to provide guidance on how to write a good SRD. Much of this guidance is based upon lessons learned in other investigations and some of it is required by NASA procedures. The text that follows should largely be considered advisory but since it is either based upon regulation or hard experience, PI's are strongly encouraged to follow these suggestions closely.

This document describes the organization of a SRD and contains a sample table of contents from an SRD with associated descriptions of sections where appropriate. PI's are not required to follow this format but the elements presented must all appear in the SRD.

Definition of Science Requirements and Science Objectives

The reference point for the experiment definition process is the peer reviewed objectives of the experiment. The objectives in the original proposal should be clarified and extended into set of discrete objectives from which the experiment requirements and success criteria can be developed. To be useful for this, the objectives must be quantitative and scoreable (i.e. it should be possible to compare the post facto experiment results with the objectives and make a quantitative determination as to whether this objective was achieved. The concept is that the general scope of the objectives presented at SCR must be consistent with the peer-reviewed objectives in the proposal however it is understood that the specific objectives will be clarified as the flight experiment concept is developed. At SCR, the objectives receive a second level of scrutiny and are essentially fixed, with few changes allowed, at that point. All requirements must address these peer-reviewed objectives. Measurements or requirements that are not necessary to meet the objectives cannot be required and are inherently “desired additions”.

The requirements for the flight investigation are defined in terms of science requirements. The purpose of the science requirements is to provide the engineering team with the information they need to define the operating conditions, hardware, software and operational requirements and to provide the science review team with the information they need to determine if the measurements and procedures will achieve the scientific goals of the approved investigation. In general the PI knows more about the science of the measurements he/she wants and the engineering team knows more about the feasibility of implementing various technologies in flight hardware. The PI specifies in the most fundamental terms possible what is to be measured or controlled and the engineering team determines how to implement the requirement. These requirements should be discussed in detail in the body of the SRD and should be summarized in a Science Requirements Summary Table. The comparison of the detailed requirements with those in the table is facilitated if the text discussion follows the table with section heading that match sections of the table. Ideally, the SRD should contain only requirements in fundamental science terms (with pass/fail criteria that can be used to define the hardware) and all design and implementation should be left to the project team. However, due to the distribution of skills and knowledge, PI experience base, and the fundamental difficulty of specifying some requirements, some deviation from this model will occur. The various ways to provide requirement specifications are listed below.

1. Fundamental specifications

   Identify the parameter being measured or controlled and the

   a. Measurement sensitivity, accuracy and repeatability.
   b. Spatial and temporal resolution, accuracy, and frequency (sampling rate and number of measurements per unit spatial dimension).
   c. Spatial and temporal domain (field of view or length of experiment) and any other specifications appropriate to the parameter being measured or controlled.

   These requirements must be individually traceable to the approved objectives and supporting modeling/analysis. In principle, this is all that is required to specify a requirement. Concessions in other requirements to achieve this requirement should be stated (blocked view, holes etc.) The fundamental requirements should not specify a technology (see item #3).

Approach Number 1 should be attempted for all requirements. In cases where this is not possible the two alternate methods below should be considered.

2. Functional Specifications (not preferred)
   If the requirement is truly functional in nature (i.e. the hardware must produce some desired but hard to quantify result) an alternate approach is to specify 1-g tests, which can be used for acceptance testing of the engineering design. The acceptance criteria must be objective and quantitative. Use of low-g testing for a functional specification of this sort can be considered if the project deems it feasible. Functional specifications of this sort must be individually traceable to the approved objectives and supporting modeling/analysis. An example of a functional requirement is the imaging of a low gravity flame that has not been previously studied so luminance and spectral data are unavailable. In this case, the camera sensitivity requirement might be defined in terms of a being able to image a particular dim flame produced in low gravity testing which the PI believes will be comparable to what will be seen in flight.

3. Optional Description/design information
   To simplify the project team's work, it is natural for the PI to suggest a proposed approach. Included in this proposal can be the assumption of verification of requirements by the PI (i.e. build it this way and I will assume the temporal resolution analysis). This description can be as detailed as desired but does not replace Item #1. If there is inherent difficulty in the requirement, it is helpful for the PI to provide design approaches but the project team has the option of pursuing other designs that they can show meet the fundamental or functional requirements (# 1 or #2). An example would be for thermocouple measurements: "use wire of diameter x and distance from sheath to bead of y and coating properties z and the PI will assume responsibility for radiative corrections and temporal response issues".

4. Optional enhancements ("desirements")
   The PI must carefully limit the items that are declared to be requirements but it is appropriate to include desired enhancements that the project team will consider including if possible.

Items that are in reality operational suggestions and hardware reliability suggestions should be treated as such and not be included in the science requirements. For example, monitoring the laser power is an operational suggestion, the fundamental requirements is to deliver laser energy whose power level is know within x%. Likewise verification or on orbit testing of hardware are operational suggestions if the data from the testing is not normally needed for the science data analysis.

Science requirement specification, detailed suggestions:

Problems may occur in the final verification of flight experiments because science requirements were poorly defined. These can usually be covered by waivers or a memorandum of understanding, but the following suggestions can help to avoid mistakes.

Range:

Range should be specified in terms of what is actually needed, not in terms of typical instrument ranges. The minimum range should not be zero but the minimum accuracy needed. Accuracy should be in terms of percent of reading not % of full scale since the scale of the instrument is not known at the time the requirement is specified. Accuracy should be stated in end to end terms and be what is really needed and not a value picked from a catalog on hand

Concentrations:

Confusion often occurs over how to specify the accuracy of a concentration requirement, due to confusion over the meaning of a % error on a % specification. Suggested language is to put the requirement in fraction terms e.g. Mole fraction instead of %. i.e.

To specify a range from 19% to 21% it could be either

0.2 mole fraction +/- .001 or 0.2 mole fraction +/- 5%.

Definition of Science Success Criteria

The science success criteria section of the SRD presents in brief tabular form the fraction of the science requirements and test matrix that must be accomplished to achieve complete success, substantial success and minimal success. In drafting these, the following criteria should be used.

Complete success: achievement of all peer reviewed objectives

Substantial success: achievement of the most important or a significant fraction of the objectives

Minimal success: achievement of a single objective or collection of enough data to produce a paper published in an archival journal.

Definition of Hardware Success Criteria

Due to uncertainty about the long-term microgravity behavior of the phenomenon being studied, it is possible for the hardware to function perfectly while the experiment doesn't achieve any of the science objectives. It is also possible for the experiment to produce unforeseen success. Since the Project Manager has no control over the science it is the responsibility of the PI to specify levels of hardware performance which, if met, and the science behaves as expected, will allow the experiment to meet the corresponding levels of science success.

Example:
Complete success will be achieved if the interferometer, the color video camera and the ignitor all function normally for all test points.

Substantial success will be achieved if interferometer, the color video camera and the ignitor all function normally for the first 6 of the 12 test points.

Minimal success will be achieved if the color video camera and the ignitor function normally for the first 3 of the 12 test points.

Following the flight, the PI, the PS, and possibly the science panel will be asked for an assessment of the experiment based both upon the success criteria and whether the experiment should be considered a success based upon the actual results that were achieved.

The following table of contents is a suggested way to organize the contents of a SRD. Other approaches are possible but the approach followed below is helpful because by putting the objectives early in the document, it allows the reader to consider the literature survey, work to date, requirements and success criteria with the final objectives clearly in mind.

SCIENCE REQUIREMENTS DOCUMENT

TABLE OF CONTENTS

- **NOMENCLATURE (if appropriate)**
- **ACRONYMS (if appropriate)**

1.0 INTRODUCTION AND BACKGROUND

1.1 Brief Overview of Scientific Topic

1.2 General objective of the overall program (ground and flight component)

1.3 Brief literature Survey emphasizing the ground based work of the PI (emphasizing importance of objectives)

1.4 Current status of understanding (emphasizing importance of objectives) and key Issues where knowledge is still lacking

2.0 Flight Experiment

2.1 Objectives and hypothesis of the flight investigation

These objectives must be discrete and quantifiable. Concepts like “study”, “observe”, and “phenomena” are not good choices whereas “determine if a hypothesis is valid,“ correlate,” “validate,” etc. are typically more concrete and can be quantitatively compared to the original objectives.

2.2 Approach (how the objectives will be met)

2.2.1 Experimental approach and top-level configuration (in broad terms) Test matrix (in broad terms i.e. gases, fuel types, inerts etc.)

2.2.2 Science Data end products

The science data end products are the graphs, analyses, correlations etc that the PI plans with the data after the flight. This section should present these end products and show that they form the necessary and sufficient set to meet the science objectives. A table listing the objectives and the associated end products and test groups is suggested.

2.3 Anticipated Knowledge to be Gained, Value, and Application (at the end of the experiment data analysis (L + 18 months)

3.0 EXPERIMENT REQUIREMENTS

3.1 Science Requirements Summary Table

This can be in tabular form or bulleted form. Generally bulleted form uses less space and is easier to read and allows more flexibility. The table should be organized into sections which are then duplication in order by explanatory text which provides detail and rationale for the requirements. A possible grouping of requirements is given below but the requirements should be organized in a manner that makes sense for the particular experiment.

3.2 Detailed discussion of the requirements and their justification

3.2.1 Experiment Configuration

3.2.2 Experimental Operating Conditions

3.2.3 Experimental Monitoring Measurements

3.2.4 Experimental Diagnostics

3.2.5 Operational Requirements (data, possible operational approach)

3.2.6 Microgravity Requirements

3.3 Detailed test matrix

List every test point with all appropriate parameters. It is understood that parameters may be changed based upon in-flight results but an initial plan should be in place. The test points must be prioritized and notation to indicate which objective they relate to is also helpful.

3.4 Success Criteria

3.4.1.1 Science success Criteria

3.4.1 Minimal Success

3.4.2 Significant Success

3.4.3 Complete Success

3.4.2 Hardware success Criteria

3.4.2.1 Minimal Success

3.4.3 Significant Success

3.4.4 Complete Success

4.0 JUSTIFICATION FOR EXTENDED DURATION MICROGRAVITY ENVIRONMENT

4.1 Limitations of Terrestrial (1g laboratory) Testing

4.2 Limitations of Drop Towers and Aircraft

4.3 Need for Accommodations in the Space Station, Space Shuttle, or Sounding Rocket

4.4 Limitations of Modeling Approaches

5.0 Science Management Plan

5.1 Hardware development and operations plan

5.2 Post Flight Data analysis Plan

The PI must present detailed plans and procedures showing how the data will be analyzed and processed to produce the science data end products. This discussion must be sufficiently detailed that the scope of the effort can be determined by the reader and the ability of the PI to perform the work can be determined. The PI must demonstrate that, the PI team, combined with the project team, have the expertise to produce the science data end products. This is most easily shown by example analyses and calibration results showing PI and project teams have produced the science data end product with acceptable quality. Extensive discussion of diagnostics is often best captured in appendices.

6.0 REFERENCES

7.0 APPENDICES

Modeling Status/Description
Validation/demonstration of diagnostic systems
Ongoing ground-based work to support RDR and beyond

APPENDIX E

Signature Page For The Science Requirements Document

Title of Experiment:

Date:

Revision:

Principal Investigator	Signature	Date

PI's Address:

CONCURRENCE

NASA Glenn Research Center:

Project Scientist	Signature	Date
Project Manager	Signature	Date
Discipline Lead Scientist	Signature	Date
Discipline Program Manager	Signature	Date

NASA Headquarters:

Enterprise Discipline Scientist	Signature	Date

APPROVAL

Enterprise Lead Scientist	Signature	Date